Event-by-event Fluctuations of the Radial and Elliptic Flow

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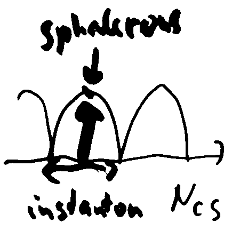
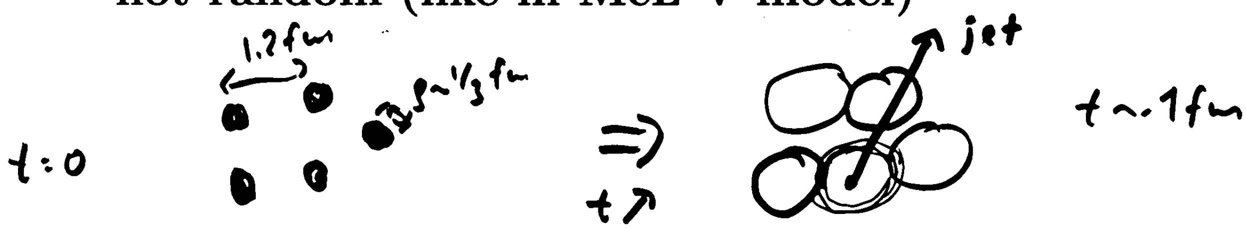
- – Topological cluster scenario in brief
- – Event-per-event fluctuations of m_t slopes due to clustering
- – fluctuations of v_2 due to clustering
- – Filamentation?

New "explosive" scenario in brief

- – Non-perturbative tunneling in the QCD vacuum are described by instantons, paths under a barrier



- – Parton collisions at the semi-hard scale, $M = 2-3GeV$, perturb instantons with certain probablity, and those absorb a non-zero energy
- – This energy eventually appears in form of specific gluomagnetic objects I would call the Turning States (generalizing sphalerons of electroweak theory)
- – Those are found to be very explosive (early extra push). They decay into a spherical expanding shell of field which eventually becomes ~ 3 gluons plus $\bar{u}u\bar{d}d\bar{s}s$ (early entropy/QGP composition)
- – Many (up to 70 per unit y) are produced in (central) AuAu but during the first fm/c: the field is not random (like in McL-V model)

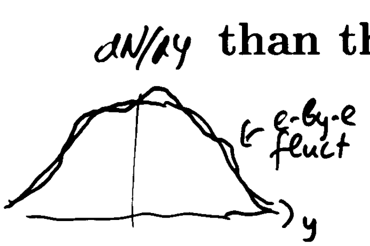


- – Jets fly through those spherical shells and get a kick from its coherent field, with rather large probablity. (jet quenching)

Event-by-event Fluctuations of the Radial Flow

E.Shuryak- HOW QUANTUM MECHANICS OF THE YANG-MILLS FIELDS MAY HELP US UNDERSTAND THE RHIC PUZZLES. hep-ph/0205031
also CERN workshop 2001

- – Cluster production induce *event-by-event fluctuations* because their number is significantly smaller than the number of particles. $N_{clust} \ll N_{particles}$



$$\frac{\delta dN_{clust}/dy}{dN_{clust}/dy} \sim \left(\frac{1}{dN_{clust}/dy}\right)^{1/2} \tag{1}$$

- – expect the particle density at mid-rapidity of RHIC AuAu central collisions to fluctuate by about by 0.05.

- –The next step is to estimate the expected fluctuations in hydro expansion velocity:

$$\frac{\delta v_t}{v_t} = \underbrace{\frac{\delta dN/dy}{dN/dy}}_{\text{drives}} \underbrace{\frac{\partial log(v_t)}{\partial log(dN/dy)}}_{\text{follows}} \tag{2}$$

- –The so called m_t slopes, or effective temperatures T_{slope}, contains v_T via the so called *blue shift factor*

$$T_{slope}/T_{true} = \sqrt{\frac{1+v_t}{1-v_t}} \tag{3}$$

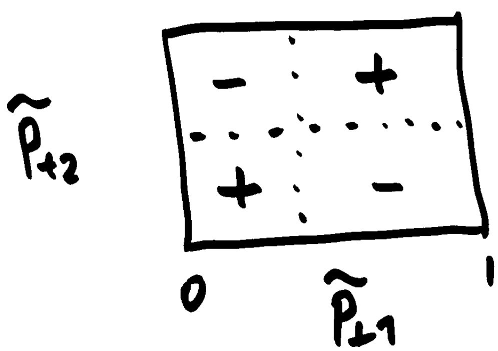
$$\frac{\delta T_{slope}}{T_{slope}} = \frac{\delta v_t}{1-v_t^2} \tag{4}$$

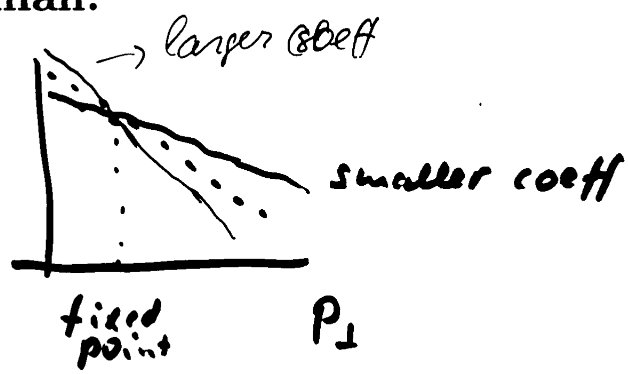
2% for p!

about 0.01 in central AuAu collisions. A relative increase in fluctuation in STAR relative to NA49 is indeed of the magnitude corresponding to about 1 per cent "slope fluctuations" for the central heavy ion collisions.

→ map on $[0,1]^2$ $P(\tilde{p}_1, \hat{p}_2)$

- – Further test: Trainor plot - two-body correlation. Slope fluctuation produce positive correlation when two trasnverse momenta are either both small or both large, but a negative one if one momentum is large and one small.





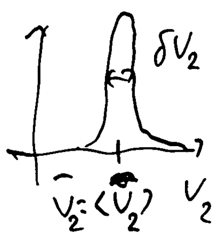
a pattern for "flow fluct." to look for

Fluctuations of Elliptic Flow

$\boxed{\text{not due to Binning in } B \text{ etc}}$

Stanisław Mrówczyński+ES, in progress

- –**Motivation: sheds more light on the system dynamics at an early stage.**
- –**Experimental motivation: v_2 is always determined e-by-e**
- – **One must carefully distinguish single-particle from multi-particle or event distributions. The elliptic flow averaged over a whole sample of events is $\langle v_2 \rangle$ while $\bar{v}_2$ is inside the event. $\langle v_2 \rangle = \overline{v_2}$ but $\langle v_2^2 \rangle \neq \overline{v_2^2} = 1/2 + \bar{u}_4/2$.**



The event-by-event fluctuations of the elliptic flow are given as

$$\mathsf{Var}(v_2) = (\delta v_2)^2 = \langle v_2^2 \rangle - \langle v_2 \rangle^2 \,. \tag{5}$$

- – Statistical Noise (N independent particles)

$$\langle v_2 \rangle = 0 \,, \qquad \langle v_2^2 \rangle = \frac{1}{2N} \,. \tag{6}$$

Consequently, $\mathsf{Var}(v_2) = 1/2N$. N is the detected multiplicity

$\delta V_2^{\text{noise}} \simeq 1\%$ for $N \simeq 5000$

- –Fluctuations of v_2 due to topological cluster formation The number of clusters as a function of N_p can be desribed as a power dependence

$$N_{clust}(N_p) = N_{clust}(N_p^{max})(\frac{N_p}{N_p^{max}})^{\alpha} \tag{7}$$

with the power α which ideally (for hard collisions) would be 4/3 but in reality is somewhat closer to 1.1-1.2.

The next step is simple, and is quite analogous to the estimate of the e-by-e fluctuation of the radial flow.

$$\frac{\delta v_2}{v_2} = \underset{\text{drives}}{\frac{\delta dN/dy}{dN/dy}} * P_h \Bigg| \overset{\text{follows}}{P_h \equiv \frac{\partial log(v_2)}{\partial log(dN/dy)}} \tag{8}$$

The first *stochastic* factor is the relative multiplicity fluctuation which drives the fluctuations, while the second *dynamical* factor P_h shows how a change in entropy transfers into v_2. P_h is obviously different for various secondary hadrons h which can be used to test the idea further.

ES QM99 page 122c

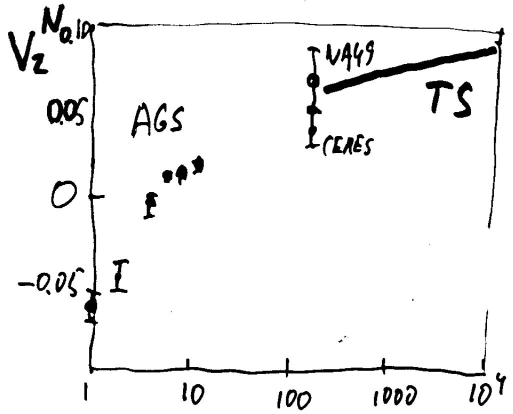


Fig 2

Prediction - V_2 will grow
Because of QGP push
$\frac{p}{\varepsilon} \nearrow$

- RQMD, UrQMD (softness) $v_2 \searrow$ factor 2
- HIJING (NO collectivity) $V_2 \approx 0$ or even < 0 at small $p_\perp$!

leaney, Lauret, Dinmyar
nucl-th/0110037

Hydro+RQMD

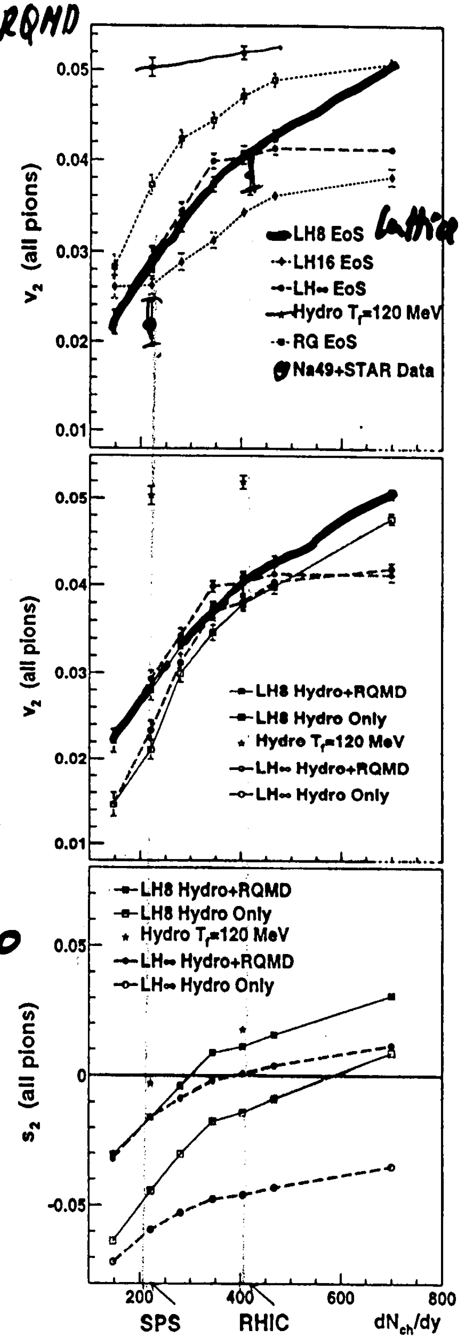


FIG. 24: Panels (a)-(c) show three related quantities a function of the total multiplicity in a PbPb collision b = 6 fm. (a) shows the integrated elliptic flow v_2 of p ons for different EOS and freezeout conditions; (b) shows tl

Is hydro flat? Only $\frac{dP}{d\varepsilon}$ = const

No

$\frac{V_2}{\varepsilon} \sim \frac{dN}{dy}$ low density Limit?

Not even here!

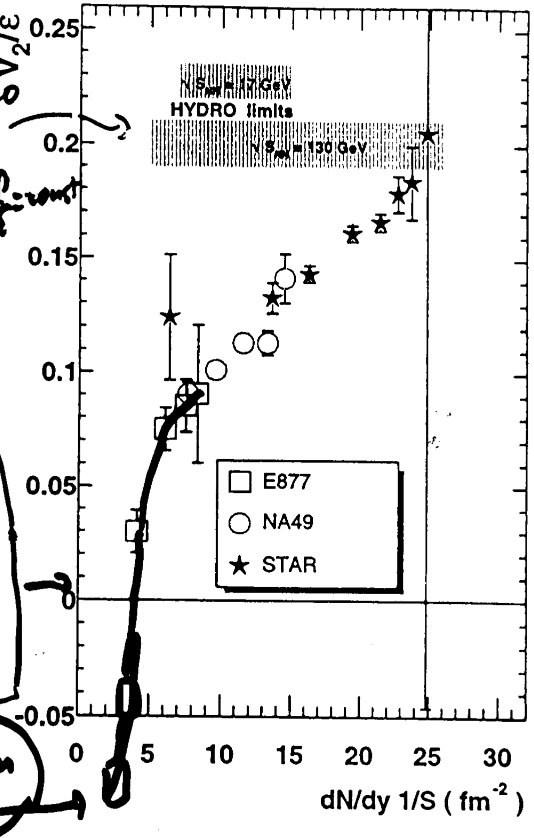


FIG. 22: v_2/ε as a function of charged particle density in A + Au collisions. Data are from E877 at the AGS (squares) NA49 at the SPS (circles), and STAR at RHIC (stars). Th AGS and SPS data have been obtained by conventional flov analysis. The STAR measurements are at $\sqrt{s_{NN}}$ = 130 GeV and correspond to the final corrected elliptic flow based o 4th-order cumulants, and we assume $dN/dy = 1.15dN/d\eta$ The horizontal shaded bands indicate the hydrodynamic lim its for different beam energies[40].

STAR nucl-ex/0206001

"dependence do not agree with hydro But LDL ... "

- – Combining expressions above, we put the reulting expression in the following form

$$\frac{\sqrt{2N}\delta v_2 - \overset{\text{noise}}{1}}{v_2} = \sqrt{\frac{2N(N_p^{max})}{N_{clust}(N_p^{max})}}\, \overset{1/2}{f_{clust}} \overset{0.4}{P_h} \left(\frac{N_p}{N_p^{max}}\right)^{\overset{1.2}{-\alpha/2}} \qquad (9)$$

not true for $N_p/N_p^{max} < 0.2$

where we have mulitiplied all by $\sqrt{2N}$ and in the l.h.s. subtracted the statistical noise. Note that a combination $N f_{clust}/N_{clust} \equiv N_{p/c} \approx 9$ is number of partons per cluster.

The magnitude of P_h can be rather reliable calculated in hydrodynamical or cascade models. We used Teaney-L-S: $P_\pi \approx 0.4$ (P Kolb gets less, ~ 0.13)

Connecting all factors together and going to the maximum at $N_p/N_p^{max} = .2$ one finds that the r.h.s. of this expression can reach about <u>0.2.</u> (We remind that this is in units in which the statistical noise is 1.)

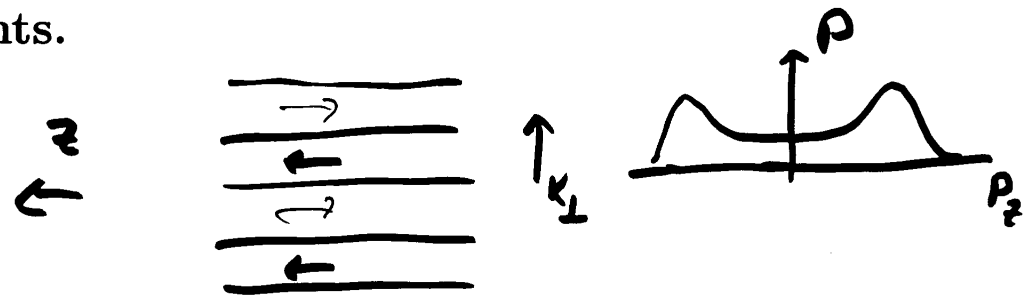
(This is much larger relative widening of the width than e.g. is the case for e-by-e mean p_t fluctuations, measured long ago by NA49.)

Filamentation instability

Mrówczyński -PRC 49, 1994, 2191

$P(\vec{p})$

- – When the momentum distribution is strongly elongated in one direction, say along the z i.e. the beam axis, the system has a tendency to split into the filaments along z with the current flowing in the opposite directions in the neighbouring filaments.



- – the color Lorentz force acts on the charges which form the currents. It appears that the currents get focused and the current magnitude grows. This is the filamentation instability.
- –The breakdown of the azimuthal symmetry of the system may happen event for central collisions !

- – the trajectories of charge particles are focused in the centres of the filaments. Therefore, according to the Liouville theorem/uncertainty relation the distribution of the momentum in the direction perpendicular to the filaments, say along the x–axis, has to expand to conserve the phase space volume.

• –modelling

$$\psi(x,y) \sim \exp[-\frac{x^2+y^2}{4R^2}]\,\underbrace{\cos(kx+\alpha)}_{\text{filamentation}}\,, \qquad (10)$$

where R is the system transverse radius.

$$P(\phi) \sim [e^{2R^2k^2\cos^2\phi}+1]\,. \qquad (11)$$

Such fluctuations do not scale with multiplicity as $\delta v_2 \sim 1/\sqrt{N}$ and should be looked at central collisions. Can probably get goòd limits on filamentation or find it (?).